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Comparing the gain of the Ne K-a inner-shell X-ray laser using the X-FEL to drive the kinetics with photo-ionization versus photo-excitation

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Disclaimer

Comparing the gain of the Ne K-α inner-shell X-ray laser using the X-FEL to drive the kinetics with photo-ionization versus photo-excitation

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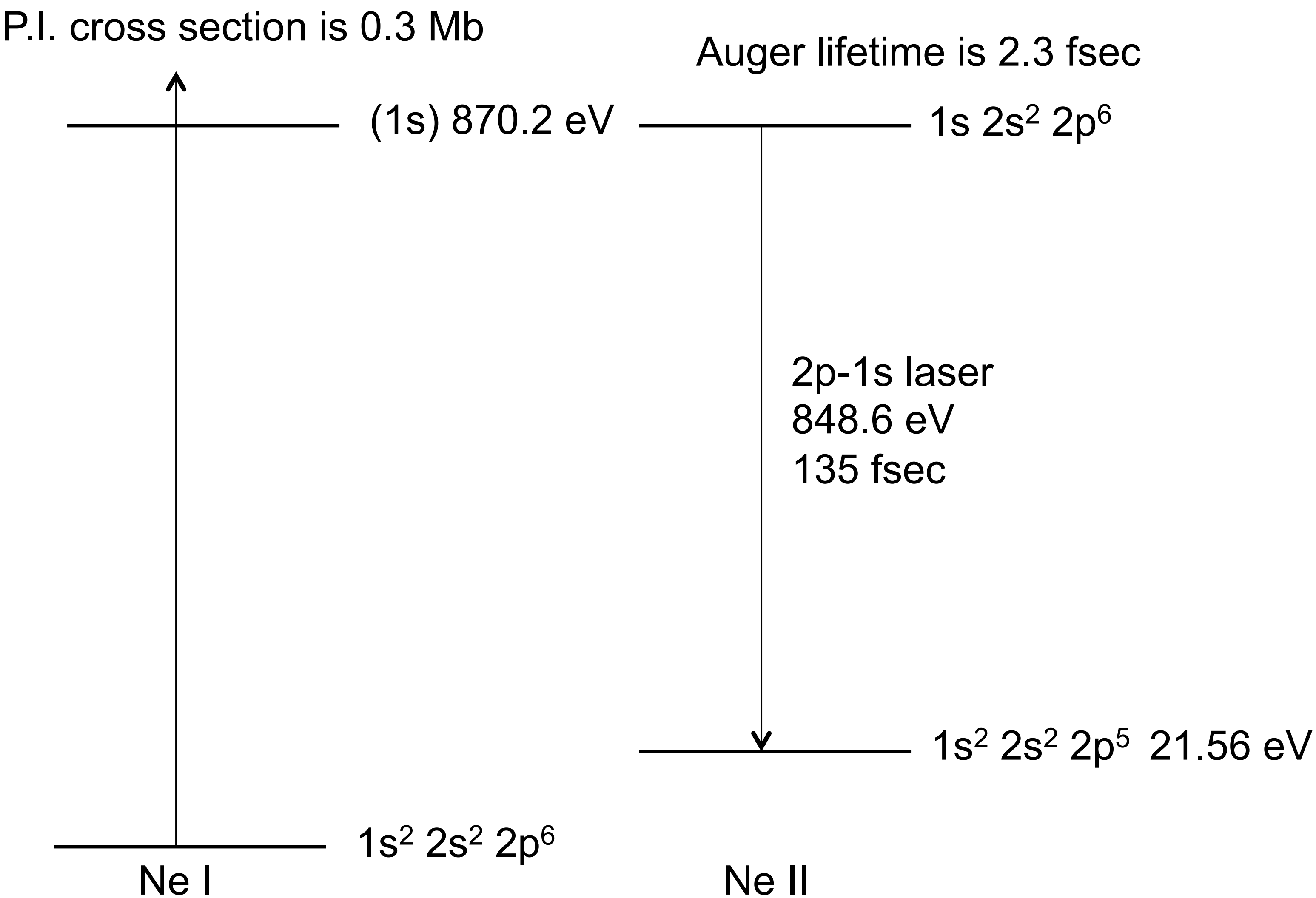
Can resonant photo-excitation allow us to produce inner shell X-ray lasers more efficiently?

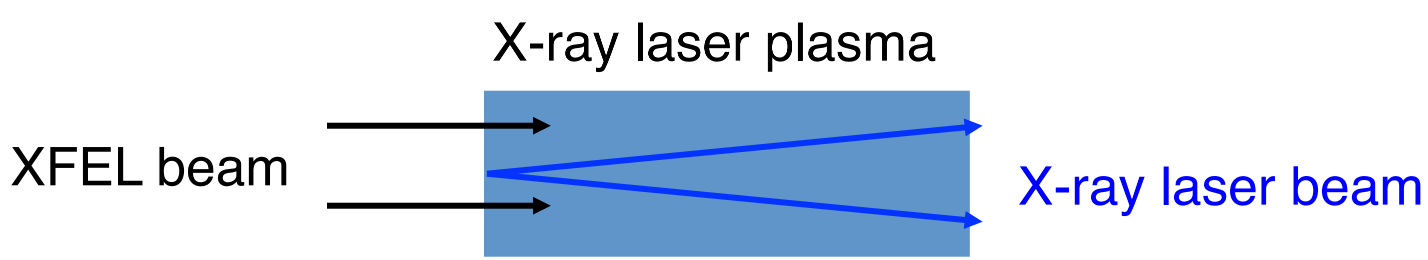
- Review the photoionization pumped inner-shell Ne X-ray laser
- Describe Ne model that includes photo-excitation processes
- Model an inner-shell Ne XRL pumped by photo-excitation
- Examine sensitivity of Ne XRL gain to XFEL linewidth and duration
- Discuss future possibilities for X-ray lasers driven by X-FEL's

Photoionization of a 1s electron in neutral Ne I creates a highly excited state of singly ionized Ne II that lases on the K-α line at 848.6 eV as demonstrated at LCLS-XFEL



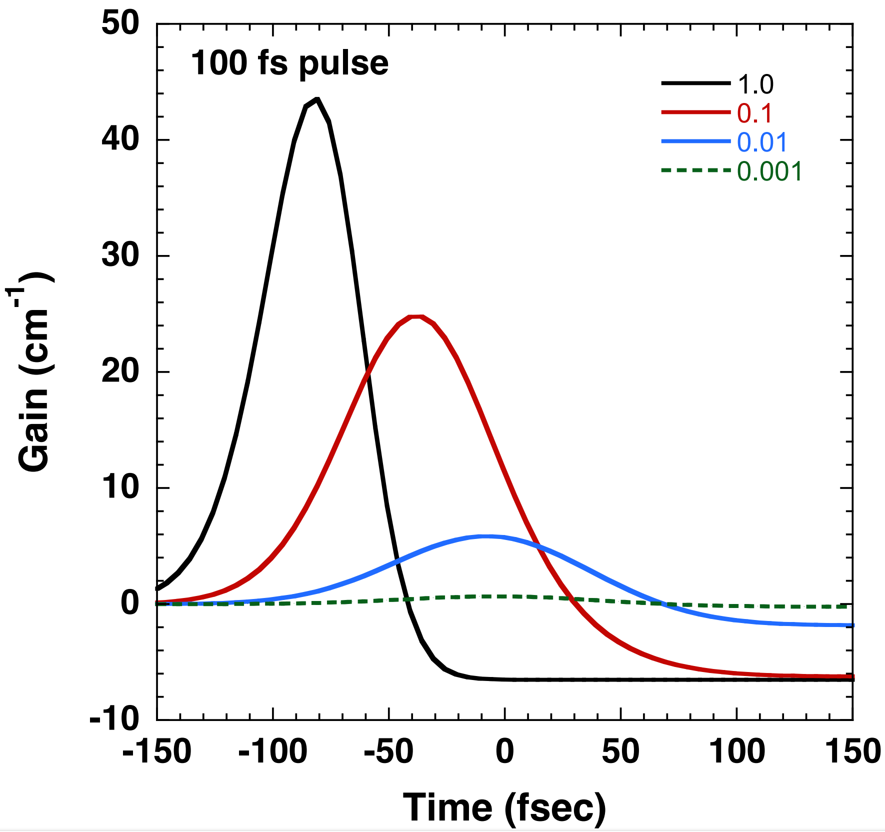
LCLS XFEL can be used to longitudinally pump an X-ray laser plasma and replace a traditional line source

Consider an XFEL beam with 10^{12} photons in 100 fs pulse with 0.1% bandwidth focused to 1 μm spot as the baseline drive
Gives flux of 10^{33} photons/[sec cm^2]



Photoionization of 1s electron in Ne I with 875 eV XFEL can create large gain on K-α line of Ne II at 848.6 eV that can be increased by reducing time duration of XFEL

Baseline XFEL beam has 10^{12} photons in 0.9 eV linewidth focused to 1 µm spot
Figures look at sensitivity to reducing number of photons by multiplying photon flux by number from 1 to 0.001
Time is relative to peak of XFEL pulse: consider 100 fs vs 1 fs FWHM XFEL pulses



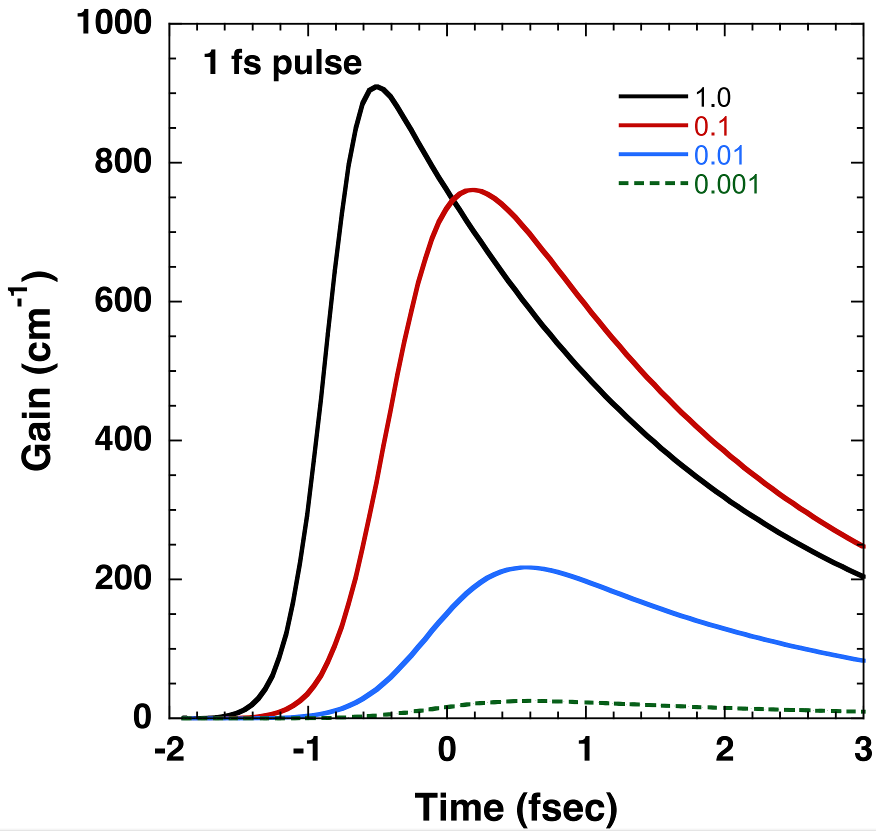


Photo-excitation of the 1s-3p transition in neutral Ne I creates a highly excited state of neutral Ne I that lases on the K-α lines at 848.96 eV

P.E. cross section is 18 Mb

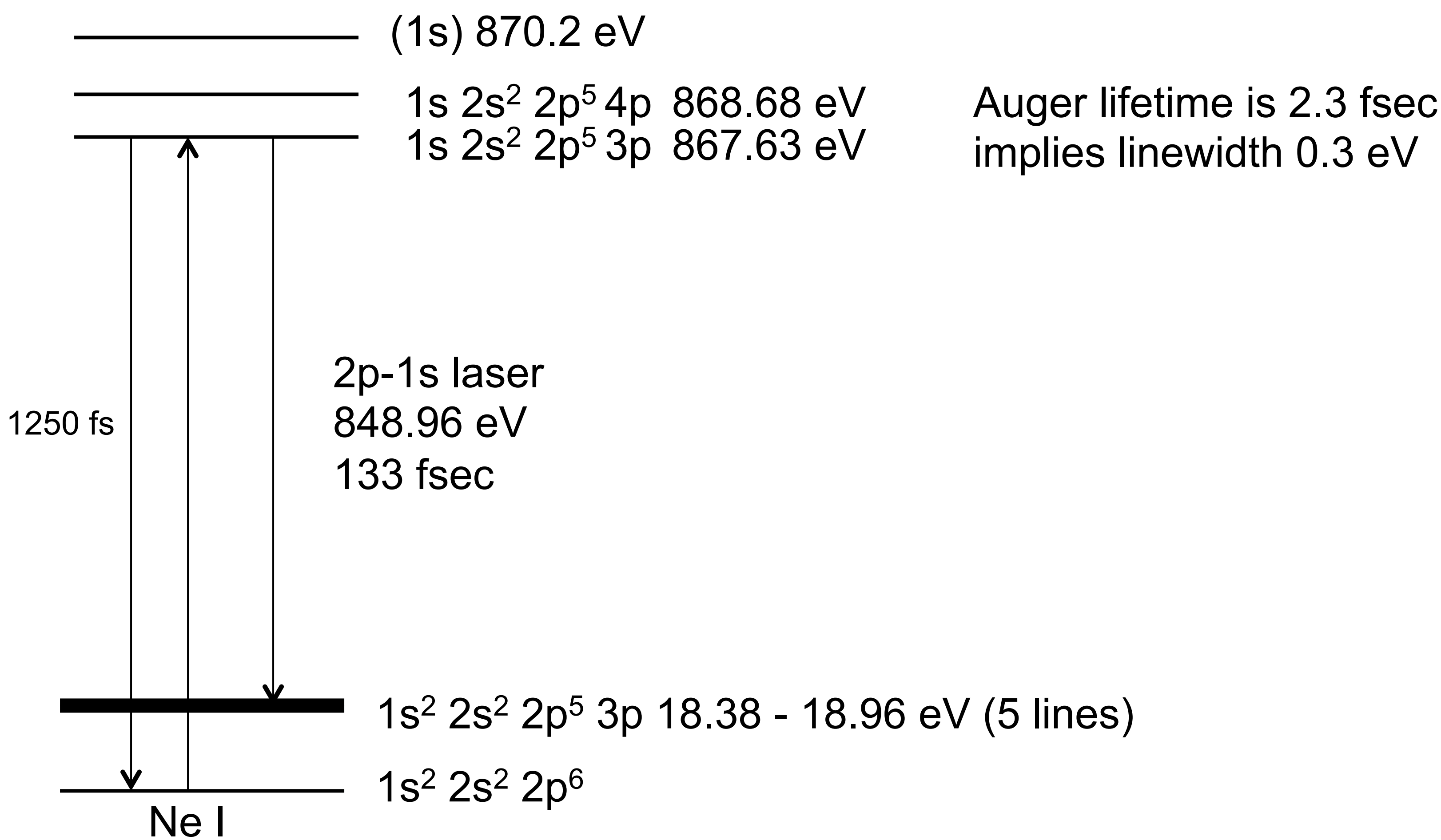


Photo-excitation of the 1s-3p transition in neutral Ne I could pump a Ne XRL at 849 eV using much less energy than the photoionization driven laser

Consider an XFEL beam with 10^{12} photons in 100 fs pulse with 0.1% bandwidth focused to 1 μm spot as the baseline drive
Gives flux of 10^{33} photons/[sec cm^2]
Photoionization rate is 3.0×10^{14} / sec for XFEL at 875 eV
Photo-excitation rate is 7.5×10^{15} / sec for XFEL tuned to 1s-3p
Experiments had L=0.28 cm and $N_{ion}=2 \times 10^{19}$/cc

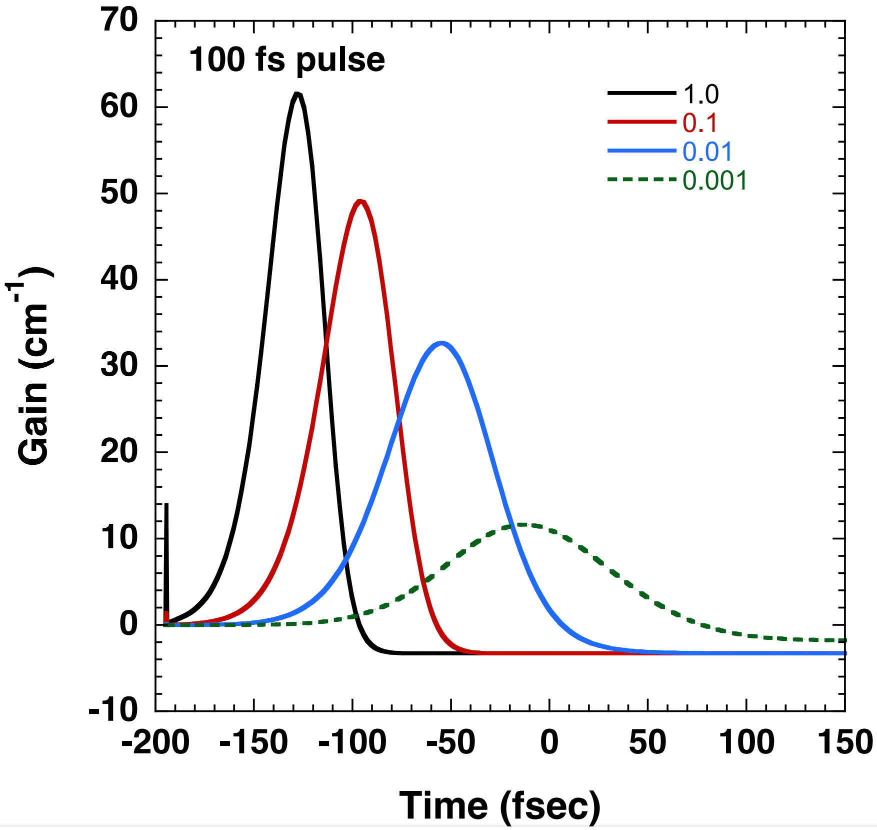
Advantages of photoionization:
1. Not resonant so all of energy used to drive photoionization
2. Insensitive to bandwidth of XFEL

Advantage of photo-excitation:
1. Much higher excitation rate than photoionization

Disadvantage of photo-excitation:
1. Need to tune XFEL to be resonant
2. Require narrow bandwidth matched to linewidth of transition
3. Higher opacity on line being pumped

Photo-excitation of 1s-3p line in Ne I with 867.6 eV XFEL can create large gain on K-α line of Ne I at 849 eV that can be increased by reducing time duration of XFEL

Baseline XFEL beam has 10^{12} photons in 0.9 eV linewidth focused to 1 μm spot
Figures look at sensitivity to reducing number of photons by multiplying photon flux by number from 1 to 0.001
Time is relative to peak of XFEL pulse: consider 100 fs vs 1 fs FWHM XFEL pulses



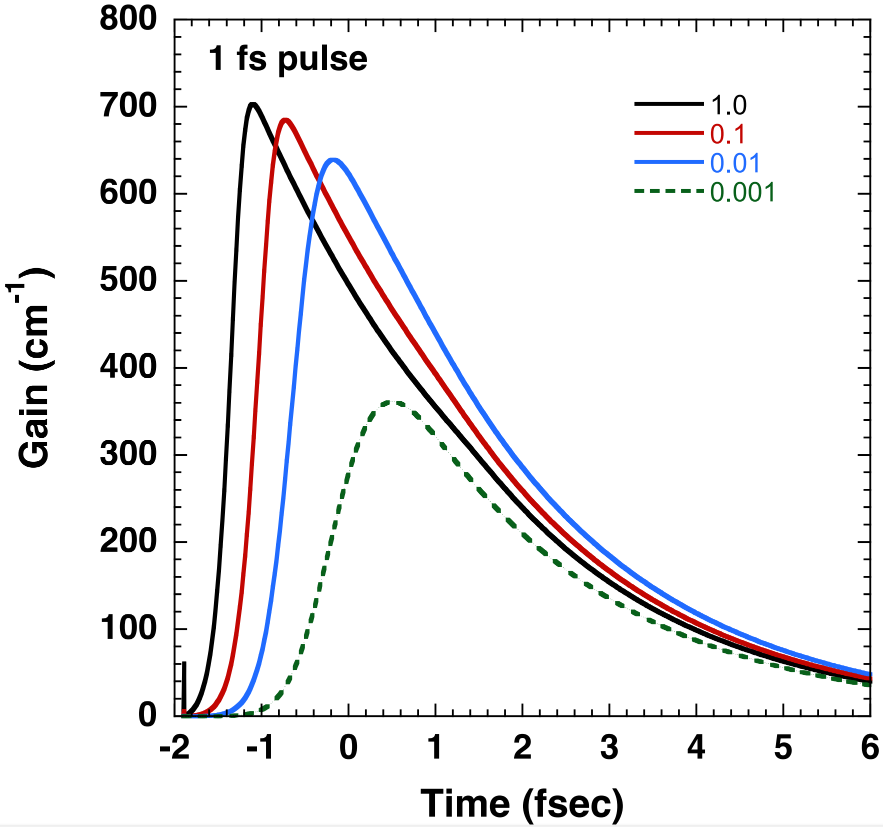
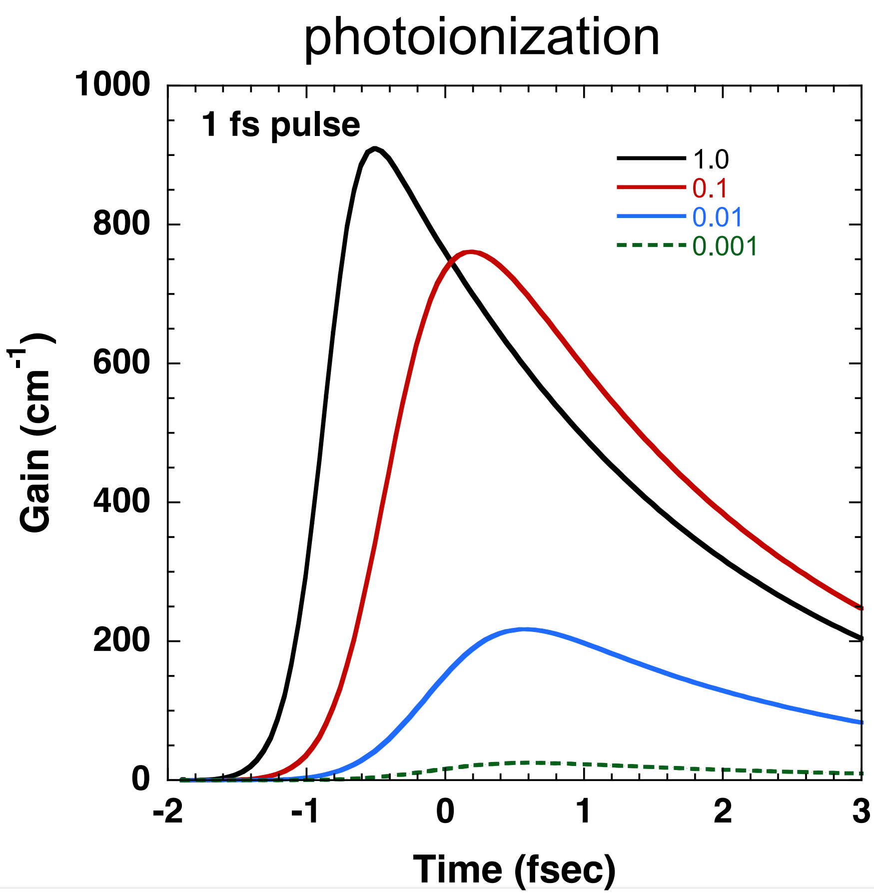
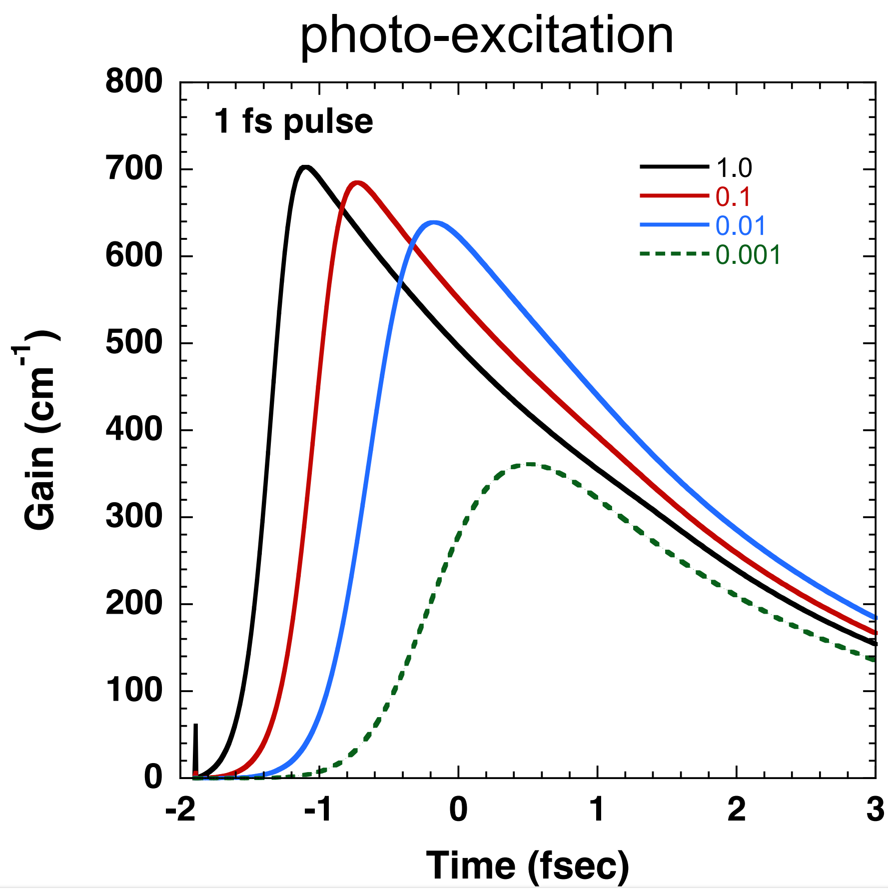


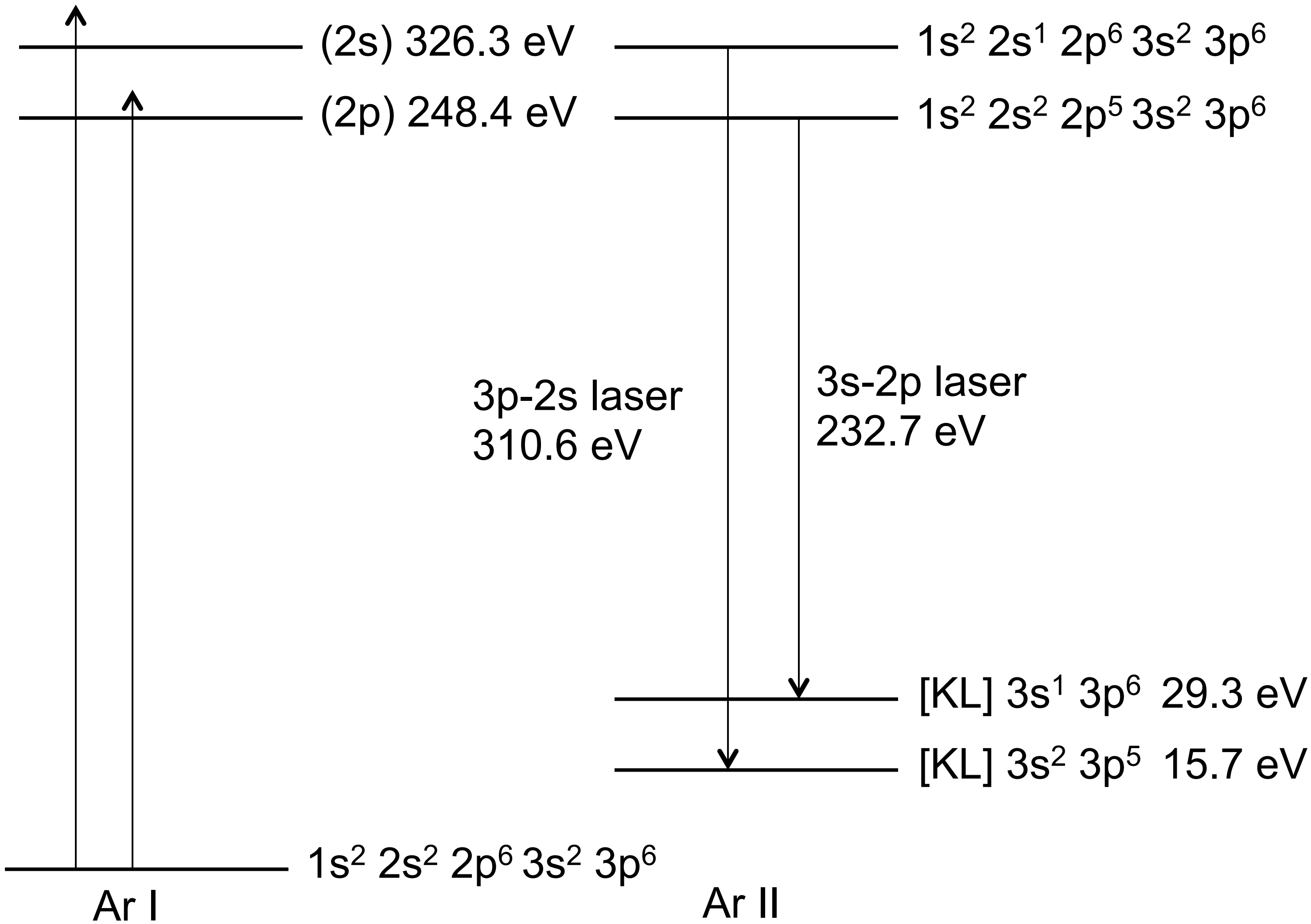
Photo-excitation of 1s-3p line in Ne I with 867.6 eV XFEL can create larger gain at much lower flux than using photoionization of 1s electron in Ne I at 875 eV

Baseline XFEL beam has 10^{12} photons in 0.9 eV linewidth focused to 1 µm spot
Figures look at sensitivity to reducing number of photons by multiplying photon flux by number from 1 to 0.001



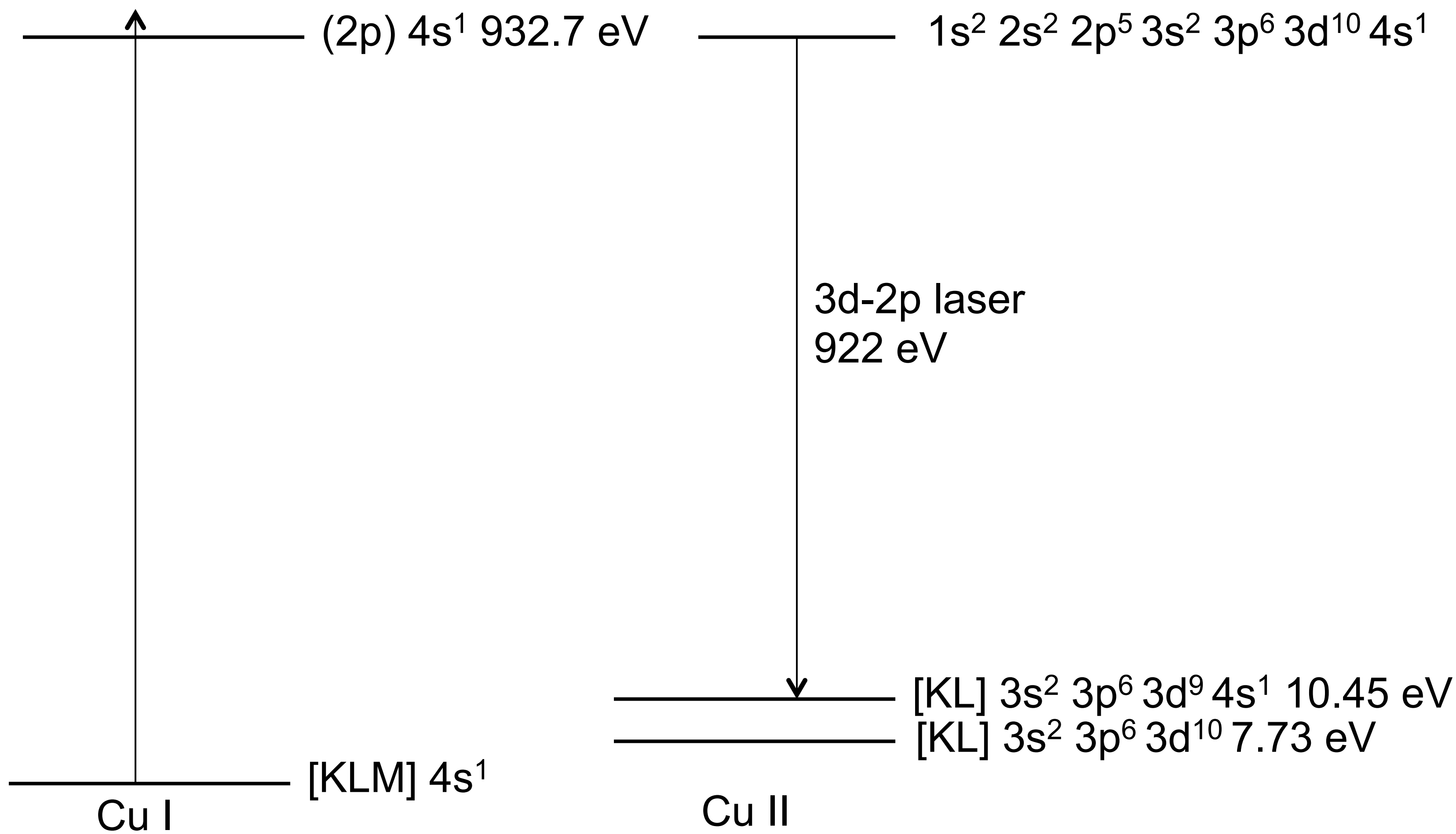


Photoionization of a 2p or 2s electron in neutral Ar I creates a highly excited state of singly ionized Ar II that could lase on the 3s-2p or 3p-2s lines near 233 and 311 eV



Photoionization of a 2p electron in Cu I (or Cu II) creates a highly excited state of Cu II (or Cu III) that could lase on the 3d-2p line near 922 eV

Photo-excitation of 2p to 4d level would also drive 3d-2p laser



Resonant photo-excitation could allow us to produce inner shell X-ray lasers more efficiently

- Reviewed the photoionization pumped inner-shell Ne X-ray laser
- Described Ne model that includes photo-excitation processes
- Model an inner-shell Ne XRL pumped by resonant photo-excitation
- Reducing the pulse duration from 100 fs to 1 fs increases the gain significantly for both the photoionization and photo-excitation driven inner shell Ne laser
- Driving the inner shell Ne laser with resonant photo-excitation can reduce the flux requirements by several orders of magnitude
- Reducing the linewidth of the XFEL to match the linewidth of the resonant photo-excitation transition should further reduce the flux requirements
- New inner shell schemes that lase on 3-2 transitions using L-shell photoionization look promising for future